FAST & ACCURATE PREDICTION OF ANTENNA-SPACECRAFT MULTIPATH EFFECTS

Interim Report

JPL Task 1015

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A. OBJECTIVES

1. Phase 1

The objective of this research project (Phase 1) is to develop a new, fast and accurate electromagnetic (EM) solver [1] of UHF antenna-spacecraft performance (multipath) that significantly reduces the time and memory (e.g., 100 to 1000 times faster and 100 to 1000 times less memory) required to create and iterate an all-metal, antenna-spacecraft design.

2. Phase 2

The Phase 1 effort is necessarily limited to modeling metal-only spacecraft structures because the required theory for efficient (fast and accurate) modeling of radiation and scattering from non-metallic materials is not yet available. An actual spacecraft consists of metallic and non-metallic materials (e.g., composites), hence the primary objective of Phase 2 (proposed for 2003 DRDF funding) will be to develop a new, fast and accurate EM solver for non-metallic materials as well. To further reduce the design time for computing multipath for a full size, multimaterial spacecraft at frequencies up to 2 GHz, a parallel processing capability (Beowulf architecture) will also be added in Phase 2.

3. Background

In recent years, spacecraft antenna design has been a process often requiring many expensive iterations before an acceptable design is obtained. At present, predictions of the combined antenna-spacecraft multipath performance are quite limited, and a mockup of the vehicle with the antenna must be built and tested. In the future, fast and efficient computational modeling of antenna-spacecraft EM performance must play a larger role in the antenna design process and these cut-and-try methods must be used less.

In our approach, we seek to develop accurate and efficient EM solvers of surface integrals based on the Magnetic Field Integral Equation (MFIE) as well as the corresponding Electric Field Integral Equation (EFIE), and their combination [2]. In attempting to develop accurate and efficient integrators for these surface integrals, two main problems need to be addressed, namely, accurate evaluation of the singular *adjacent interactions* – without undue compromise of speed, and fast evaluation of the voluminous number of *nonadjacent interactions* – without compromise in accuracy.

Our adjacent, high-order integrators are based on *analytical resolution of singularities*. The only alternative approach in existence is based on strategies of refinement around singularities (Canino et al. [3]). The approach we introduce is advantageous since it does not require costly setup manipulations and it leads to substantially more accurate and faster numerics.

The accelerator we introduce for the *nonadjacent interactions*, in turn, is related to two of the most advanced FFT methods developed recently [4]. A number of innovations in our approach, however, lead to very significant memory savings and faster numerics. Our design reduces, significantly, the size of the required FFTs – from N^2 to $N^{4/3}$ points, with proportional improvement in storage requirements and operation count. Further, it results in super-algebraic convergence of the equivalent source approximations *as the electrical size of the body (spacecraft) is increased*.

B. PROGRESS AND RESULTS

1. EM Field Solver

So far, a basic field solver for the acoustic (scalar) problem has been implemented. The results are similar to what can be expected from a full Maxwell solver. These results, for speed, efficiency and accuracy, are presented in Table 1 below. We present comparisons of accuracies and timings produced by our methods versus the well-known Fast Illinois Solver Code (FISC) [5] which uses the Fast Multipole Method [6]. We can see from Table 1 that our new algorithms run with considerably less RAM and yet with a comparable speed.

2. Geometry – Surface Representations

Calculation of EM multipath interactions with our new algorithm will require detailed information on the spacecraft surfaces and edges. This includes not just surface locations, but in some cases continuous higher-order surface derivatives. These data are not readily available from standard CAD programs because these programs focus primarily on mechanical design. Our progress so far with respect to surface representations includes:

i. Edges and corners - Geometry representations for complex spacecraft must include singular-type surfaces with intricate coordinate transformations. Our approach is applicable to such surfaces. In Table 2, for example, we present results on the performance of our approach for the singular scatterers of Figure 1. Errors are computed through convergence studies which, in turn, were checked through comparison with solutions for the same geometries, with “incident fields” given by point sources within the scatterer – for which the solution is the field of the point source itself.

ii. Spacecraft geometry - The generic lander structure shown in Figure 2 has been implemented. This structure is similar to the test mockup used for measurement of MER Lander UHF antenna performance.

C. SIGNIFICANCE OF RESULTS

The results so far indicate that for scalar acoustics our new, fast and accurate solver technique is performing substantially better than current conventional methods. The work remaining in Phase 1 will focus on implementation and testing of the Maxwell EM (vector) field solver for antenna-spacecraft structures of metallic composition. At the end of this Phase 1 (July 2003), we expect to deliver an initial capability for multipath analysis of complete antenna-spacecraft structures with metallic properties. A follow-on Phase 2 is proposed elsewhere (2003 DRDF call) that will bring this new solver up to full strength and speed by incorporating arbitrary dielectric materials (e.g., composites) and parallel processing.

D. FINANCIAL STATUS

The total funding for this task was $100,000, of which $20,000 has been expended.

E. PERSONNEL

Besides Dr. Vaughn Cable and Professor Oscar Bruno, other personnel involved are Caltech post docs Drs. Matt Pohlman, Randy Paffenroth, and Christophe Geuzaine.

F. PUBLICATIONS

None.

G. REFERENCES

1. Oscar P. Bruno, et al., " A Fast, High-Order Algorithm for the Solution of Surface Scattering Problems: Basic Implementation, Tests, and Applications," *Journal of Computational Physics*, No. 169, pp. 80-110 (2001).
2. Oscar P. Bruno, et al., "Surface Scattering in Three Dimensions: An Accelerated High-Order Solver," *Proceedings of the Royal Society of London*, No. 457,pp. 2921-2934 (2001).
3. Lawrence F. Canino et al., "Numerical Solution of the Helmholtz Equation in 2D and 3D Using a High-Order Nystrom Discretization," *Journal of Computational Physics,* No. 146, pp. 627—663 (1998).
4. Elizabeth Bleszynski, et al., "AIM: Adaptive Integral Method for Solving Large-Scale Electromagnetic Scattering and Radiation Problems," *Radio Science*, Volume 31, No. 5, pp. 1225-1251, Sep-Oct 1996.
5. Jin M. Song, et al., "Fast Illinois Solver Code (FISC)," *IEEE Antennas and Propagation Magazine*, No. 40, pp. 27-34 (1998).

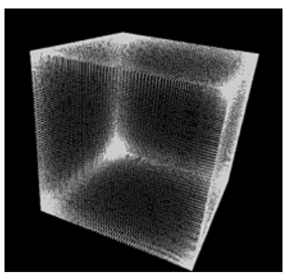
6. Ronald Coifman, et al., "The Fast Multiple Method for the Wave Equation: A Pedestrian Prescription," IEEE *Antennas and Propagation Magazine*, Vol. 35, No. 3 , pp. 7 –12, June 1993.

Algorithm	**Diameter**	**Time**	**RAM**	**Unknowns**	**RMS Error**	**CPU**
FISC	120λ	32x14.5h	26.7GB	9,633,792	4.6%	32 proc. SGI
Our Method	80λ	55h	2.5GB	1,500,000	.005%	Single 1.4GHz proc.
Our Method	100λ	68h	2.5GB	1,500,000	.03%	Single 1.4GHz proc.

Table 1. Scattering from large spheres.

Geometry	**Diameter**	**Time**	**Unknowns**	**RMS Error**	**CPU**
Cube	10x10x10	21h	96,774	.049%	Single 1.4GHz proc.
Saucer	42x42x17	53h	290,874	.0045%	Single 1.4GHz proc.

Table 2. Performance of our method on singular scatterers.



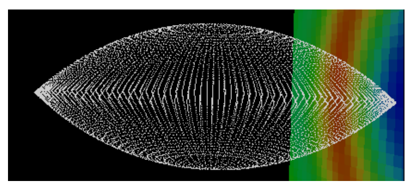


Figure 1: Two singular scattering geometries. Left: cube. Right: Flying saucer.

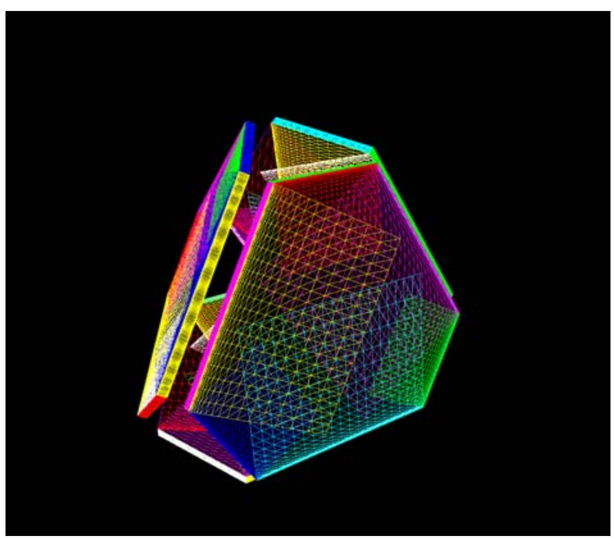


Figure 2: Basic MER Lander mockup geometry.